INTERACTIONS OF SIMULATED PARTIALLY CLOSED CRACKS WITH ACOUSTIC WAVES

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ABSTRACT

It is well known that partial contact of two rough surfaces leads to transmission of an acoustic signal across the crack, thus giving rise to a reduced probability of detection (POD). To explore the effects of such partial contact on transmission, diffraction, scattering and mode conversion of an acoustic signal, samples have been developed in which an interface simulates a true fatigue crack. Some of the effects of these interfaces on a longitudinal acoustic wave have been studied experimentally and will be reported.

INTRODUCTION

In a series of papers[1-4], the effects of a partial contact of fracture surfaces on the transmission coefficient of a longitudinal ultrasonic wave parallel to the normal to these surfaces have been reported. From the experimental and theoretical results obtained, it is clear now that localized contact (partial contact) of the two rough surfaces occurs, with the contact areas separated by small voids when the crack is under no external load. If an external tension load is applied, the voids become bigger until the crack is fully open. On the other hand, if an external compressive load is applied, the voids become smaller until they disappear completely. Even in high strength structural materials creep may occur, leading to a hysteresis in the transmission coefficient versus external stress relation.[5] It was pointed out earlier[3] that the width (W) and the distance (S) between these contact points determine strongly the transmission coefficient (t) which is given by

$$t = [1 + (\frac{\pi f \rho V_\ell}{\kappa})^2]^{-1/2},$$

where f is the acoustic frequency, ρ the density, V_ℓ the (longitudinal) acoustic velocity and κ a "spring constant" of the layer that makes up the crack (voids, and localized contact areas). A two dimensional model[3] showed κ to be a function of S and W, but this model could not be fully compared to experiments on true fracture surfaces since the contacting areas could not be independently determined. Photolithographic methods were thus employed to produce a (periodic) roughness at the interface with known topography. Model samples made using this technique have the added advantages that the acoustic wave may be longitudinal or transverse and may impinge on the surface at any arbitrary angle. First results on the effects of such a periodic (as well as a nonperiodic) roughness on the transmission coefficient will be reported. Very strong signals were observed in situations where both the transmitted as well as the scattered signal were off the normal to the interface, and were not specularly oriented with respect to one another. A second sample was prepared with an interface of unknown topography. This interface was produced by pressing two blocks together. It is thought that it resembles a true fatigue crack even closer than the one produced by photolithography; however, S and W are unknown for this second interface. Results obtained on these samples will be compared. At the present time we have no theoretical model to explain the observed effects. Therefore, we restrict ourselves to reporting the experiments and results obtained. Work on the subject will continue.

EXPERIMENTAL PROCEDURES AND RESULTS

Blocks of 1100 HO aluminum were prepared as shown in Fig. 1. Those faces of the blocks, intended to form the interfaces with another block were polished flat, followed by an electropolish. In one case, a grating was produced using photolithography. The dimensions of the grating are shown at the bottom of Fig. 1, and an actual micrograph is given in Fig. 2. Pressing the face containing the grating against a second block (both blocks are held together by four screws) produces contact along the (brighter) lands of the grating. The acoustical contact is excellent in that the material, being very soft, can flow and match the second surface. By forming an interface without grating we have determined that the reflection coefficient of such an interface is at least -55 db down from a perfect reflector.

In addition, a second sample with an interface was produced without employing photolithography. It was noted that during

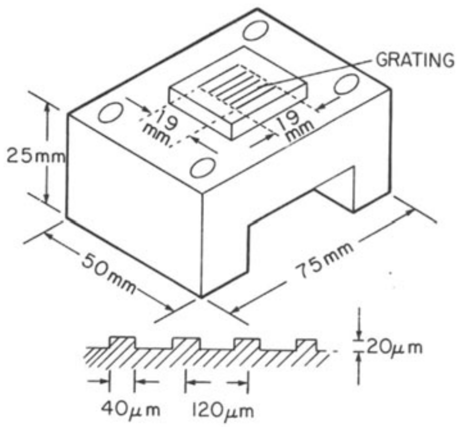


Fig. 1. Schematics of a block containing an acoustic grating. Also shown is the provile of the grating.

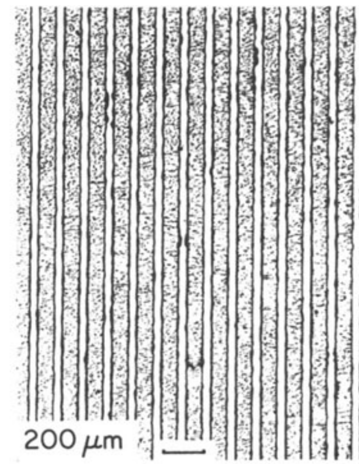


Fig. 2. Optical micrograph of the acoustic grating.

compression of two soft aluminum blocks the material at the interface strain hardens. If the blocks are taken apart after the first compression and reassembled, the interface will not be as acoustically perfect as after the first compression. Therefore, such an assembly produces an interface which is more typical of a true fatigue crack than the assembly containing the grating, although the "roughness parameters" W and S are unknown.

Furthermore, "calibration blocks" - not containing any interface - were produced for comparison with the above samples.

A picture of a block assembly containing an interface is shown in Fig. 3. The probing acoustic beam entered these blocks perpendicular to one of the flat faces to be seen in Fig. 3 and exited from the opposite block as shown in Fig. 4. The remaining

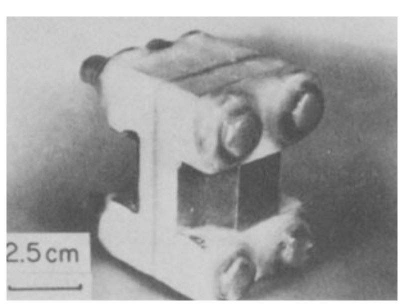


Fig. 3. Block assembly.

free surfaces of the assembled blocks were coated with wax to prevent water from penetrating into the interfaces. All measurements were performed in a water tank using 10 MHz tranducers.

In a first set of experiments, the transducers were unfocused. Typical results (in the time and frequency domain), obtained on the sample with a photolithographically produced grating, are shown in Figs. 4a-c with the acoustic beam incident at 45° to the interface containing the grating. The 45° condition was maintained throughout all experiments. In this case, the received "forward scattered" signal is very strong with the 10 MHz component remaining the dominating signal. A polar plot of the 10 MHz component, as received from the interface with grating, is given in Fig. 5 and compared with the signal received from the interface without grating, as well as that from a reference block not containing any interface. Two effects are noticeable: (1) The angular dependence of the waves scattered from the interfaces with and without grating are qualitatively similar but quite different from that received from the reference block; (2) The scattered signals from the interfaces with and without grating are relatively strong in the 90° observation direction.

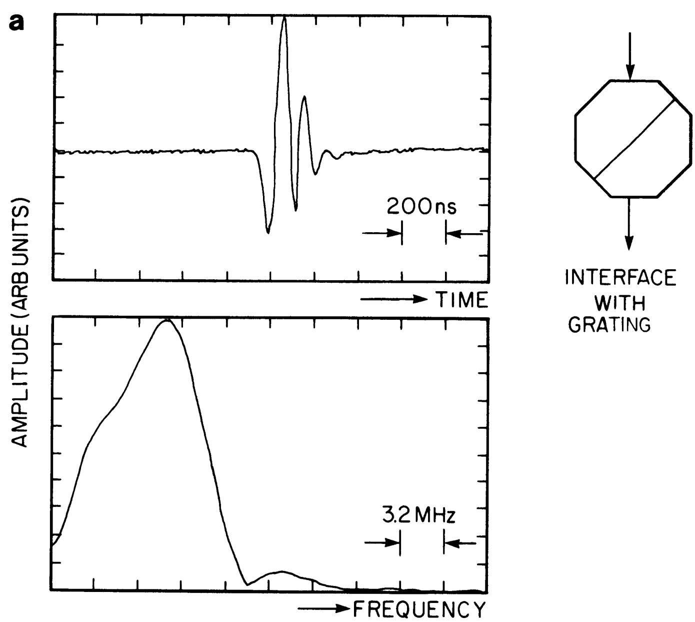
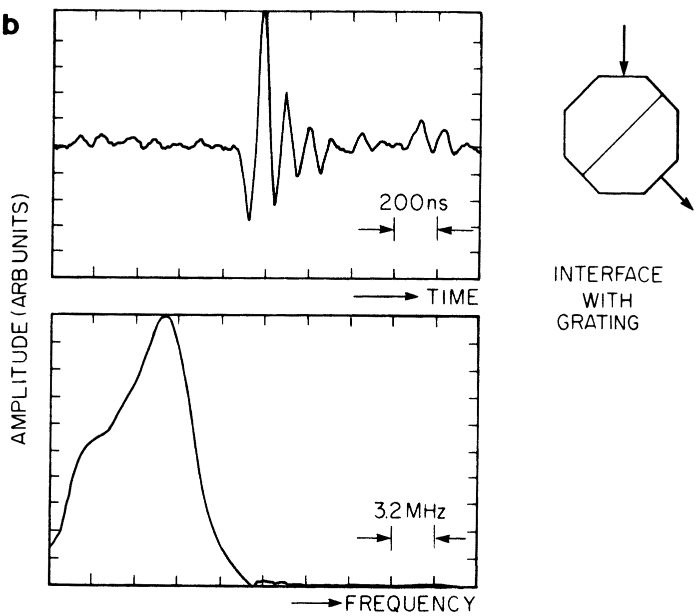
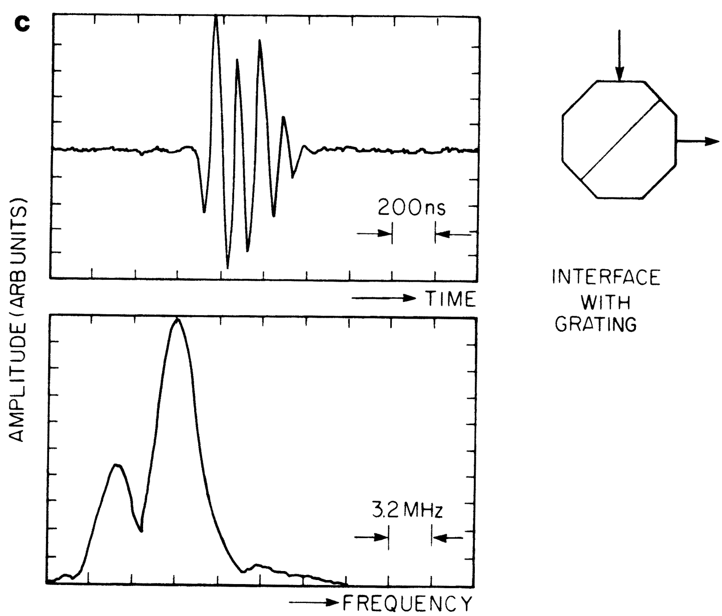


Fig. 4. Forward scattered signals in the time and frequency domains. The interface contained the acoustical grating. (Shown is Fig. 4a. Figs. 4b and 4c following page.)

b


AMPLITUDE (ARB UNITS)
200ns
TIME
3.2 MHz
FREQUENCY
INTERFACE
WITH
GRATING

c


AMPLITUDE (ARB UNITS)
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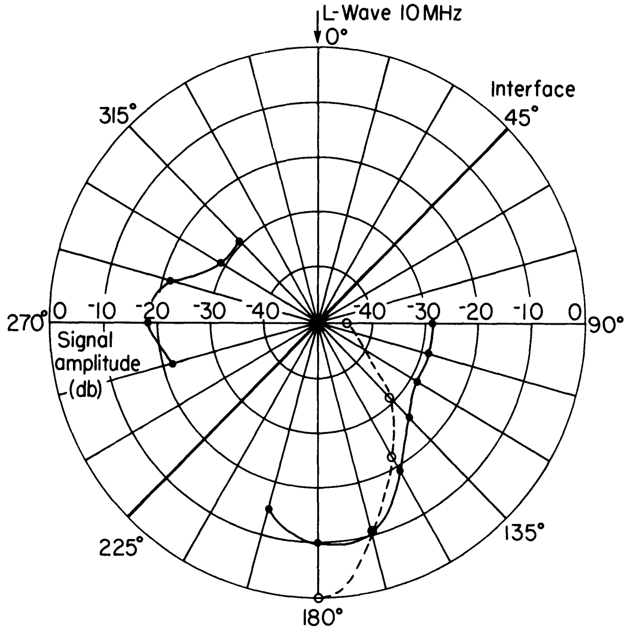

Fig. 5. Polar plot of the relative amplitudes obtained from an L-wave striking the interface under 45°. Octahedral blocks.
-••- interface without grating
-•- interface with grating
--- reference block (no interface)

At this point in the experiments, it became clear that the limited access to the interface could be bypassed by preparing a cylindrical (instead of an octahedral) outer surface. However, the transducers would then have to be focused such that the beam within the block assembly consists of plane waves. Using an arrangement as shown schematically in Fig. 6 we repeated the measurements on the block assembly containing the interface without a grating. The results, compared with those obtained from a reference cylinder (without any interface) are shown in Fig. 7, again limiting ourselves to the 10 MHz component. The results in the "forward scattered" direction are very similar to those obtained from block assemblies with octahedral faces (Fig. 5). Included in Fig. 7 are some "backscattering" results (10 MHz component) including the specular reflection from the interface (in 270° direction).

Experiments, as described above, will continue. Of particular interest will be to determine the scattering amplitude as a function of angle of incidence and the roughness parameters W and

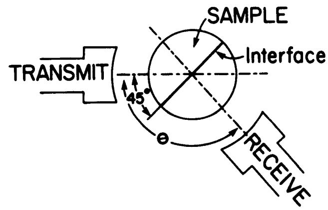

Fig. 6. Experimental setup using focused transducers to determine scattering from interfaces in cyclindrical samples.

S. We should also be able to determine mode conversions at the interfaces, as well as effects of the finite acoustic beam width. We intend to develop a theory on the interaction of such simulated partially closed cracks with acoustic waves, hoping to be able to deduce the roughness parameters[3] W and S.

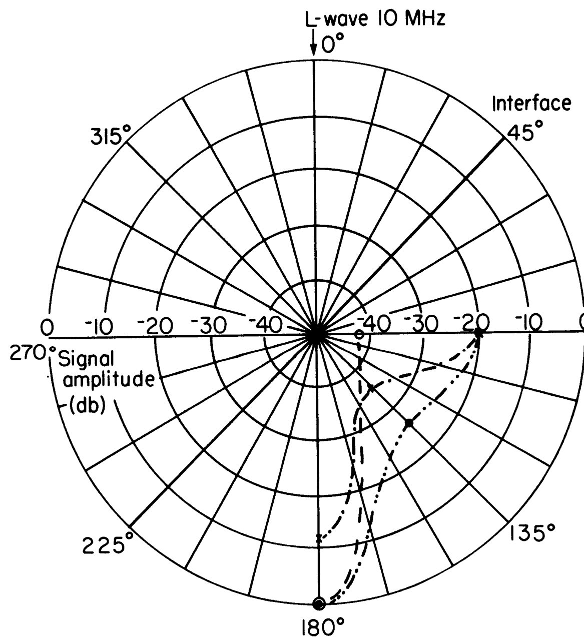

Fig. 7. Polar plot of the relative amplitudes obtained from an L-wave striking the interface under 45°. Cylindrical blocks.
—— interface without grating
--- reference block (no interface)

SUMMARY

The present experiments strongly indicate that the "forward scattered" signal from an interface, which resembles a fatigue crack, contains an angular structure which may be useful for deducing the roughness parameters of the fatigue crack. So far, only limited data have been obtained, and no theory for this "forward scattering" has been developed. However, it was shown that, using photolithographic methods, acoustic "gratings" can be produced which may assist in the validation of the theory.[3] More work is definitely needed before any quantitative conclusions can be drawn.

ACKNOWLEDGEMENTS

The authors acknowledge the help of S. M. Wheeler during the experiments. This work was supported by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Defense Advanced Research Project Agency and the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-Eng-82 with Iowa State University.

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